Partial Shading Detection and MPPT Controller for Total Cross Tied Photovoltaic using ANFIS

Donny Radianto[1], Dimas Anton Asfani[2], Takashi Hiyama[3], and Syafaruddin[4]
[1] Kumamoto University / Electric Power Engineering, Japan
[1] State Polytechnic of Malang, Indonesia, Email: ra_di_an@yahoo.com
[2] Kumamoto University / Electric Power Engineering, Japan, Email: anton_dimas@yahoo.com
[3] Kumamoto University / Electric Power Engineering, Japan, Email: hiyama@cs.kumamoto-u.ac.jp
[4] Universitas Hasanuddin, Makassar, Indonesia, Email: syafaruddin@unhas.ac.id

Abstract— **This paper present Maximum Power Point Tracking (MPPT) controller for solving partial shading problems in photovoltaic (PV) systems. It is well-known that partial shading is often encountered in PV system issue with many consequences. In this research, PV array is connected using TCT (total cross-tied) configuration including sensors to measure voltage and currents. The sensors provide inputs for MPPT controller in order to achieve optimum output power. The Adaptive Neuro Fuzzy Inference System (ANFIS) is utilized in this paper as the controller methods. Then, the output of MPPT controller is the optimum power duty cycle (α) to drive the performance DC-DC converter. The simulation shows that the proposed MPPT controller can provide PV voltage (V_{MPP}) nearly to the maximum power point voltage. The accuracy of our proposed method is measured by performance index defined as Mean Absolute Percentage Error (MAPE). In addition, the main purpose of this work is to present a new method for detecting partial condition of photovoltaic TCT configuration using only 3 sensors. Thus, this method can streamline the time and reduce operating costs.**

Index Terms—**Photovoltaic, TCT, MPPT, duty cycle, optimum power.**

I. Introduction

Sustainability and development of new energy resources are one of the important issues globally. It is due to the rise in world oil prices, the protocol that each country is encouraged to increase alternative sources of energy and the demand of ever increasing energy needs. Photovoltaic (PV) system is one of the potential renewable energy sources which being continuously developed and attracted much attention worldwide. Global photovoltaic market is also happening in Europe where there are additional electricity capacity of photovoltaic systems installed. Besides Europe, a country that ranks third in the world in 2009 in the world photovoltaic market is Japan where the 484 MW have been installed. Meanwhile, some countries are showing significant growth in 2009 was Canada and Australia, while six countries that is considered promising in developing photovoltaic industry is Thailand, Mexico, South Africa, Marocco, Brazil and Taiwan[1]. The reason why photovoltaic's are so popular and can compete with other potential energy sources are abundant, no pollution, and freely available [2]. In addition, the photovoltaic system may support the lack of power in distribution system either by grid-interconnected or just stand alone systems. Nevertheless, there are still many potential challenges to increase the penetration or capacity of PV system in our grid and to promote PV technology worldwide. Basically, photovoltaic module consists of PV cells which can convert solar light directly into electricity when it is illuminated by sunlight. Although the photovoltaic cell has several advantages, but the results of the photovoltaic cell also has limitations, especially on the voltage and current. To anticipate this, the photovoltaic cell is often connected and combined into a single into a photovoltaic module. Typically, a photovoltaic module consists of 36 PV cells connected in series and parallel depending on the desired output characteristics.

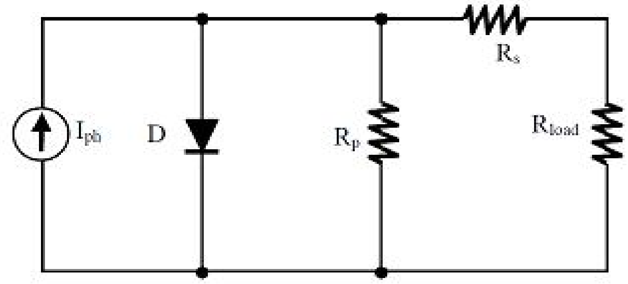

Figure 1. Solar cell or photovoltaic module equivalent circuit

Two things that greatly affect photo current (I_{ph}) are the solar irradiance and temperature. According to Fig. 1, the diode actually represents the p-n junction of semiconductor devices. Other parameters, such as n and I_s in (1) represents diode ideality factor and saturation current, respectively. Also, the series and parallel resistances are expressed by R_s and R_p. Applying Kirchhoff's law in equivalent circuit, the general equation for PV cell/module can be derived as follows. This equation is very important to generate I-V and P-V curves of cell or module.

$$I = I_{ph} - I_s\left[\exp\left(\frac{q(V + IR_s)}{nN_s kT}\right) - 1\right] - \frac{V + IR_s}{R_p} \tag{1}$$

where, I is the output current of the PV module, N_s is the number of solar cells in series in a module, V is the terminal voltage of module, q is the electric charge (1.6 x 10^{-19} C), k is the Boltzmann constant (1.38 x 10^{-23} J/K) and T is the cell temperature (K). The expansion of general equation can be further defined for saturation and photo currents as follows:

$$I_s = I_{s,ref}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_G N_s}{kn}\left[\frac{1}{T} - \frac{1}{T_{ref}}\right]\right) \tag{2}$$

DOI: 01.IJEPE.03.02.24

$$I_{ph} = \left[I_{ph,ref} + \mu_{iSC}(T - T_r) \right] \frac{G}{1000} \tag{3}$$

In (2) and (3), G is the incident solar irradiation on the PV module, EG is the material band gap energy of the solar cell material, ìisc is the temperature coefficient of the short circuit current. Other parameters, such as series resistance, parallel resistance, diode ideality factor are only determined once for reference operating condition [2]. In essence, photovoltaic system affected by two parameters namely solar irradiance and temperature. Typical example of *I-V* and *P-V* curves are shown in Fig. 2 and Fig. 3. Fig. 2 and Fig. 3 show that when solar irradiance (G) increase so short circuit current and maximum power output will increase, respectively. This occurs because the open circuit voltage logarithmically depends on solar irradiance as well as the short circuit also proportionally affected by solar irradiance. Additionally, the photovoltaic system also affected by partial shading which this condition is often caused by environmental condition such as cloudy, snow, leaves, etc. The last point about the partially shaded condition is still the hot topics to be solved by PV system engineers. There are several ways to solve this problem, such as using different configurations of cell module, the configuration of array system (series, parallel, series / parallel, bridge link, and total cross tied). Meanwhile, this mismatch problem can be solved using bypass diode and series parallel configuration [3]. Actually, partial shading is a problem which many researchers have proposed various methods, both through the photovoltaic system modeling and validation with measurements in real time that includes the performance of the MPPT controller [4-5], PV system simulation [6], numerical algorithm [7], mathematical model for different configuration [8-11], investigating physical characteristic of photovoltaic system and parallel configuration to increase output power of PV system [12–17]. Although many methods have been proposed recently to solve partially shaded problems but they still require a lot of input variables which is used to increase the output of photovoltaic especially under partial condition. MPPT controller is designed to obtain operation voltage under partial shaded condition based on electrical data measurement. Simulation based PV module consist of 5x2 Total Cross Tied (TCT) configuration is used in this paper. There are two current measurement at series connection and one voltage sensor are utilized to provide input variable of the controller, TCT connection is used because it has several advantages compared with other configurations such as superior and more reliable[18-19] Generally, MPPT controller work together with dc-dc converter especially to track maximum power point. The MPPT controller is installed between photovoltaic module (source) and load. It was mentioned that characteristic of PV system varies with temperature and irradiance [19]. The advantage of the proposed method only uses three sensors namely current sensor 1, current sensor 2, and voltage sensor. Moreover, this method can be used as an alternative to design partial detection with few sensors which is installed in TCT configuration.

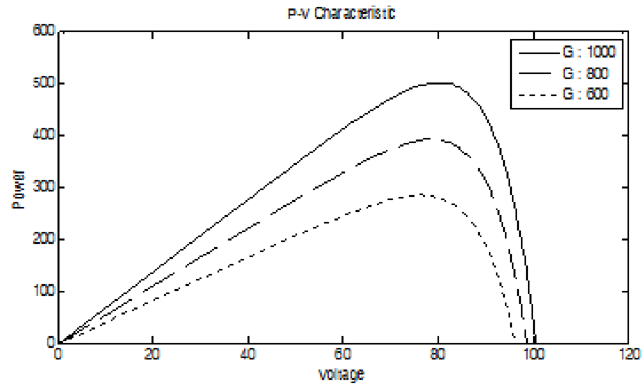

Fig. 2. P-V characteristic of photovoltaic

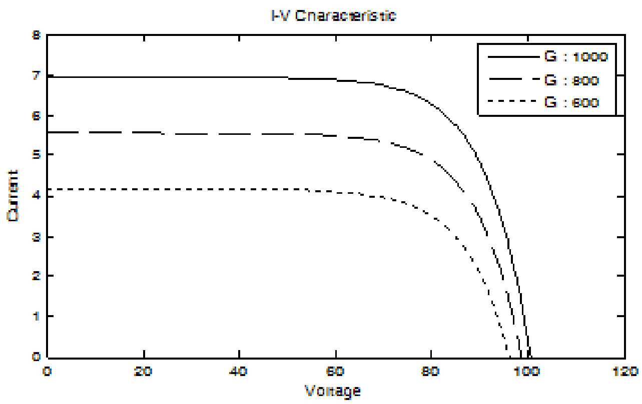

Fig. 3. I -V characteristic of photovoltaic

II. Configuration of Proposed Method

A. Total Cross Tied (TCT) Configuration

In terms of configuration technique, many methods have been developed such as simple series (SS), series paralel (SP), bridge link (BL), Honey Comb (HC), and Total Cross Tied (TCT) configuration to overcome partial conditions [19-20]. From the configuration which is mentioned above, total configuration tied (TCT) has superior configuration if compared with other configuration. This can be proven that TCT has the highest of peak power rather than other configuration (HC, BL) [19-20]. Fig. 4 shows the proposed total cross tied configuration with 5 x 2 module connections with positive and negative terminal. As shown all modules are connected each other in the way that PV module no.1 is connected with PV module no. 6, PV module no. 2 is connected with PV module no. 7, and so on. The output of the proposed total cross tied can be taken through positive (+) side and from this point the configuration can be connected with the controller. In this section, the proposed system is shown in figure 5. The system is composed of 5 x 2 total cross tied configuration, MPPT controller , and DC-DC converter. Here, there are 3 input sensor which is used to give input signal to MPPT as voltage sensor and current sensor in which for current sensor consist of two sensor such as current sensor-1 and current sensor-2. The current sensor-1 is installed in close to PV module 1 , whereas the current sensor 2 is placed in close to PV module 6.

DOI: 01.IJEPE.03.02.24

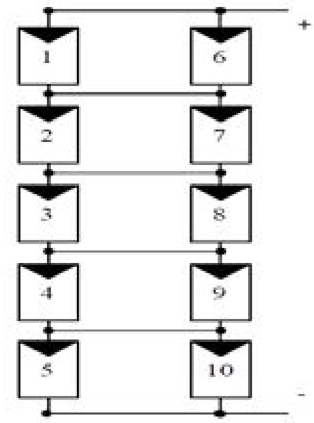

Fig. 4. 5 X 2 TCT PV array configuration

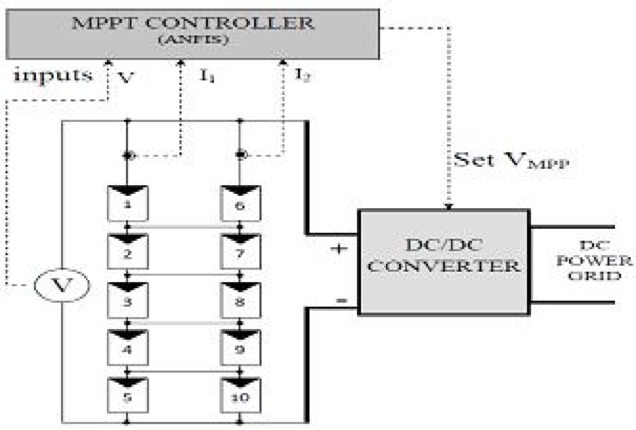

Fig. 5. The Proposed System

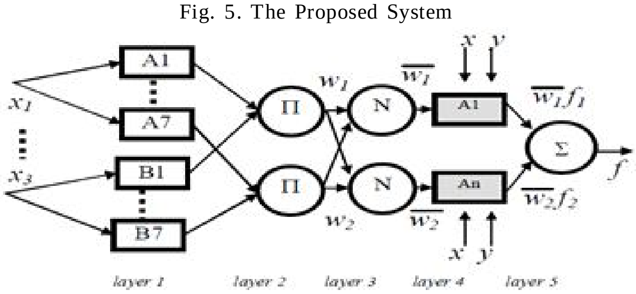

Figure 6. Architecture of ANFIS equivalent to the first order Sugeno Model

The output of MPPT is duty cycle (α) in which it is used to adjust DC-DC converter. The duty cycle (α) is often used to keep the output of MPPT in optimum condition.

B. Maximum Power Point Tracking (MPPT) Controller By Adaptive Neuro Fuzzy Inference System (ANFIS)

Maximum Power Point Tracker (MPPT) proposed here, can be used to optimize power output. MPPT itself consists of three inputs of the voltage sensor, current sensor 1 and sensor 2 and an output current in the form of duty cycle. Data obtained from both the input and the output of the MPPT is processed by Adaptive Neuro Fuzzy Inference (ANFIS). The output of the Duty Cycle is used to drive a DC - DC Converter. Basically, the ANFIS is a combination of artificial neural network and fuzzy inference system from fuzzy logic in which fuzzy logic itself is a system which can be used to enhance overall stability of multi power system [21].

The integration of ANN and FIS can be classified into three categories namely concurrent model, cooperative model, and fully fused model. In addition, ANFIS also uses hybrid learning combining backpropagation, gradient descent, least square algorithm, to identify and to optimize the sugeno system signal [22-24]. The working system of Architecture of ANFIS in fig. 6 shows that the input variables are fuzzified in the first hidden layer, whereas, the fuzzy operators are applied in the second hidden layer. In the third hidden layer the fuzzy rule base is normalized. Next, in the fourth hidden layer , the consequent parameter of the rules is ascertained. Last step, the overall input will be computed by the fifth layer. In this paper, ANFIS controller is designed with three variable input and 7 membership function each input. Variable input consist of two current variable, I_1 and I_2, and operated voltage, *V*.

C. DC / DC Converter

The output of the MPPT controller is used to activate the dc to dc converter, in which this converter works by changing the source of dc voltage to another voltage [25]. DC to DC converter powered from pulse width modulation resulting from artificial neuro fuzzy inference system (ANFIS). Dc- dc converter which is often encountered is a buck converter, boost converter, buck and boost converter. Figure 7 below is a boost dc - dc converter that serves to raise the voltage of the input voltage.

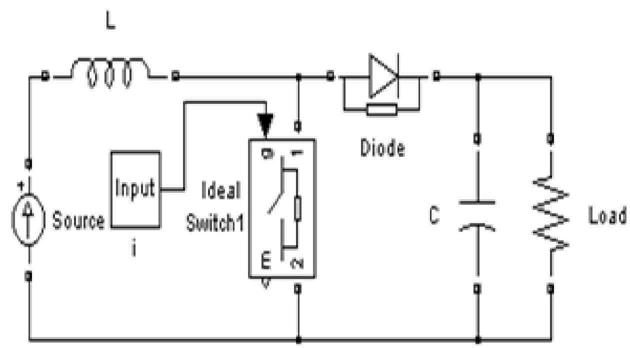

Fig. 7. Boost dc - dc Converter

III. Simulation Results and Discussion

Table 1 above shows that data set varied by 3 variable as shading case, irradiance variation, and pre-voltage. As known, shading case occur when the photovoltaic modul is in shaded condition which affected by solar irradiance. Here, there are 18 case in the shading case which is started from P1, P3, P5, P1P2, P1P7, P2P3, P3P8, P4P5, P4P10, P1P2P3, P1P2P6, P3P4P8, P1P2P3P4, P1P2P6P7, P2P3P7P8, P1P2P3P4P5, P1P2P3P6P7, and P2P3P4P7P8 , respectively. P means Photovoltaic under shadded, whereas the number behind P explain about number of PV module.

The one P means that photovoltaic module is only one. The P is three mean that the number of P is three, respectively. In column two explains about irradiance variation in which its variation range is started from solar irradiance 100 to 1000. The range of irradiance variation has 18 step which is started from one photovoltaic (P1) module to five photovoltaic modul (P2P3P4P7P8). The last column of this table explain about

DOI: 01.IJEPE.03.02. 24

pre-voltage variation which the range of this variation made from 45 volt to 85 volt and the range is also consist of 18 step according to the number of photovoltaic module. The data set is consist of 5500 case which devided by 80% training and 20% testing data for data (ANFIS) controller. Fig. 8 depict training data recognation in which there are two signal, the first signal is from V_{MPP} (no dash line), whereas the other signal is from V_{ANFIS} (dash line). The Voltage set in above figure has a range from 45.08 volt until 85.59 volt, whereas the case number has a range located between zero to 4500. Herein, The V_{MPP} is affected by three parameter namely V(Voltage), I_1 (Current One), and I_2 (Current Two). Fig. 9 clearly illustrates both the voltage set and training data activities of two V_{MPP} and V_{ANFIS} method. In addition, the fig. 9 also show the behaviour of training data recognation of both V_{MPP} and V_{ANFIS}.

Fig. 9 represents the testing data result in which these data differ from fig. 7. The voltage set used in testing data has same range with the voltage set used in fig. 9 namely from 45.08 volt until 85.59 volt.

TABLE I. DATA SET

Shading case	Irradiance variation	Pre-voltage variation
P1	100-1000	45-85
P3	100-1000	45-85
P5	100-1000	45-85
P1P2	100-1000	45-85
P1P7	100-1000	45-85
P2P3	100-1000	45-85
P3P8	100-1000	45-85
P4P5	100-1000	45-85
P4P10	100-1000	45-85
P1P2P3	100-1000	45-85
P1P2P6	100-1000	45-85
P3P4P8	100-1000	45-85
P1P2P3P4	100-1000	45-85
P1P2P6P7	100-1000	45-85
P2P3P7 P8	100-1000	45-85
P1P2P3P4P5	100-1000	45-85
P1P2P3P6P7	100-1000	45-85
P2P3P4P7P8	100-1000	45-85

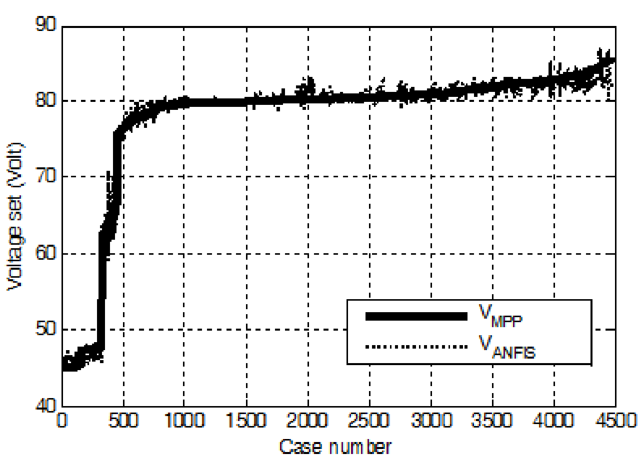

Fig. 8. Training Data Recognation

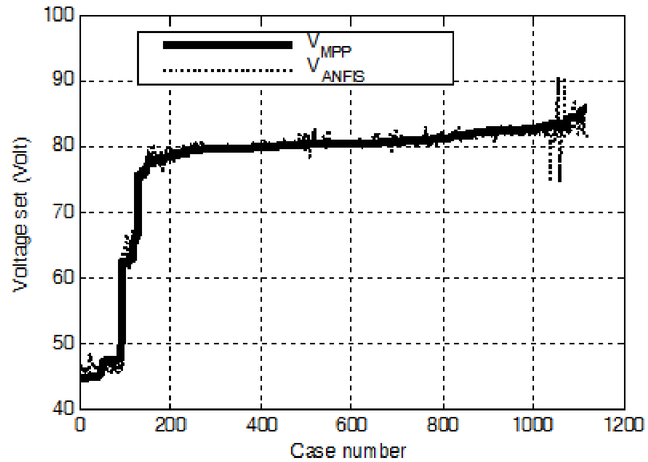

Fig. 9. Testing Data Result

However, a number of data used in case number of testing data result is lesser than data used in case number of training data recognation. Eventhough the behaviour of V_{MPP} and V_{ANFIS} in training data recognation is similar to that of V_{MPP} and V_{ANFIS} in testing data result. Performance of the proposed method is measured by Mean Absolute Percentage Error (MAPE) which is calculated as in equation 4 below [26] :

$$M = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \times 100 \ \% \qquad (4)$$

A_t: The actual value
F_t: Output of ANFIS Value
n : number of data

The MAPE calculation of data set is resulting training data set 0.82% and testing data 0.95%. From the results of these calculations, there is little difference whether of the training data set and testing data sets, so it can be said that the method presented gives optimal results and efficient.

IV. Conclusions

In this paper, the application based on detection nonlinear two parameter (voltage and current) characteristic of photovoltaic module in Total Cross Tied (TCT) configuration as well as ANFIS for MPPT Controller which is used to achieve optimum power in variation condition. The various component of model have been trained and tested by using data from the various input data of the V_{MPP} photovoltaic system. The results shows that the proposed method can obtain V_{MPP} at various operating condition of partial shadding.. The main contribution of this paper is to give alternative MPPT controller based on electrical data information of PV system. The future work is to realize the proposed method into the real experimental of PV system and applied ANFIS system in a Microcontroller or FPGA device for expert configuration.

Acknowledgment

The authors would like to thank “Departemen Pendidikan Tinggi Republik Indonesia” for providing the scholarship to continue study in Japan.

DOI: 01.IJEPE.03.02. 24

REFERENCES

[1] David Beattie, "Photovoltaic Outlook Stays Sunny. Renewable Energy.com," (2011)

[2] H.K.V. Lotsch,"Optical Science,"springer

[3] S. Silvestre, A. Boronat, A. Chouder, "Study of bypass diodes configuration on PV modules," Appl. Energy 86 (2009) 1632–1640.

[4]Nivedita Dasgupta, Ashish Pandey and Ashok K. Mukerjee,"Voltage-sensing-based photovoltaic MPPT with improved tracking and drift avoidance capabilities, Solar Energy Materials & Solar Cells 92 (2008) 1552 – 1558.

[5] T. Tafticht, K. Agbossou, M.L. Doumbia, and A. Cheriti ," An improved maximum power point tracking method for photovoltaic systems, Renewable Energy 33 (2008) 1508 – 1516.

[6] G. Walker, "Evaluating MPPT converter topologies using a matlab PV model, J. Elect. Electron. Eng., "Aust. 21 (1) (2001) 45–55.

[7] V. Quaschning, R. Hanitsch," Numerical simulation of current–voltage characteristics of photovoltaic systems with shaded solar cells," Solar Energy 56 (6) (1996) 513–520.

[8] A. Gow, C.D. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," IEE Proc. Elect. Power Appl. 146 (2) (1999) 193–200.

[9] J.A. Gow, C.D. Manning, "Development of a model for photovoltaic arrays suitable for use in simulation studies of solar energy conversion systems, in: Proc. 6th Int. Conf. Power Electron. Variable Speed Drives, 1996, "pp. 69–74.

[10] S. Chowdhury, G.A. Taylor, S.P. Chowdhury, A.K. Saha, Y.H. Song, "Modelling, simulation and performance analysis of a PV array in an embedded environment, "in: Proc. 42nd Int. Univ. Power Eng. Conf. (UPEC), 2007, pp. 781–785.

[11] A. Hovinen, Fitting of the solar cell/V-curve to the two diode model, Phys. Scripta T54 (1994) 175–176.

[12] J. Hyvarinen, J. Karila, "New analysis method for crystalline silicon cells, in: Proc. 3rd World Conf.Photovoltaic Energy Convers.," vol. 2, 2003, pp. 1521–1524.

[13] K. Kurobe, H. Matsunami, "New two-diode model for detailed analysis of multicrystalline silicon solar cells, "Jpn. J. Appl. Phys. 44 (2005) 8314–8321.

[14] K. Nishioka, N. Sakitani, K. Kurobe, Y. Yamamoto, Y. Ishikawa, Y. Uraoka, T. Fuyuki, "Analysis of the temperature characteristics in polycrystalline Si solar cells using modified equivalent circuit model," Jpn. J. Appl. Phys. 42 (2003) 7175–7179.

[15] K. Nishioka, N. Sakitani, Y. Uraoka, T. Fuyuki, "Analysis of multicrystalline silicon solar cells by modified 3-diode equivalent circuit model taking leakage current through periphery into consideration," Solar Energy Mater. Solar Cells 91 (13) (2007) 1222–1227.

[16] Syafarudin, Engin Karatepe, Takashi hiyama,"Polar coordinated fuzzy controller based real-time maximum power point control of photovoltaic system,"Renewable Energy 34 (2009) 2597 - 2606

[17] Hassaine L., "Modelisation et Simulation d'un Systeme de Conditionement de Puissance pour la Poursuite de Puissance Maximale dans les Systemes Photovoltaiques," Algeria: Memorire de Magister, Ecole Nationale Polytechnique (ENP); Juin 2003

[18] Syafarudin, Engin Karatepe, Takashi Hiyama," Polar Coordinated based real – time maximum – power point control of photovoltaic ,"Renewable Energy 34(2009) 2597-2606

[19] Yaw-Juen Wang, Po-Chun Hsu, " An investigation on partial shading of PV modules with different connection," Energy 36 (2011) 3069-3078

[20] Magdy M. Abdelhameed, Farid A. Tolbah,"A Recurrent neural network based sequential,"Mechatronics 12(2002) 617-633

[21] Takashi Hiyama, Takeshi Sameshima, "Fuzzy logic control scheme for on-line stabilization of multi-machine power system,"Fuzzy Sets and Systems (1991) 181 - 194

[22] Rasit Koker,"Design and performance of an intelligent predictive controller for a six-degree-of-freedom robot using the Elman Network," Information Science 176 (2006) 1781-1799

[23] Adel Mellit , Soteris A. Kalogirou,"ANFIS-based modelling for photovoltaic power supply system: A case study,"Renewable Energy 36 (2011) 250-258

[24] Engin Karatepe, Mutlu Boztepe, Metin Colak,"Neural Network based solar cell model,"Energy Conversion and Management 47 (2006) 1159–1178

[25] Liping Guo, John. Y. Hung, R. M. Nelms ,"Comparative evaluation of sliding mode fuzzy controller and PID controller for a boost converter", Electric Power Systems Research 81 (2011) 99–106.

[26] Jinquan Wan, Mingzhi Huang, Yongwen Ma, Wenjie Guo, Yan Wang, Huiping Zhang, Weijiang Li, Xiaofei Sun, "Prediction of effluent quality of a paper mill wastewater treatment using an adaptive network-based fuzzy inference system", Applied Soft Computing 11 (3)(2011) 3238-3246.

DOI: 01.IJEPE.03.02.24